OHIO RIVER BASIN PRECIPITATION FREQUENCY STUDY

Update of *Technical Paper No. 40, NWS HYDRO-35* and *Technical Paper No. 49*

Thirteenth Progress Report
1 October 2002 through 31 December 2002

Hydrometeorological Design Studies Center
Hydrology Laboratory

Office of Hydrologic Development
U.S. National Weather Service
Silver Spring, Maryland

January 2003

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The data and information presented in this report should be considered as preliminary and are provided only to demonstrate current progress on the various technical tasks associated with this project. Values presented herein are NOT intended for any other use beyond the scope of this progress report. Anyone using any data or information presented in this report for any purpose other than for what it was intended does so at their own risk.

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1. Introduction

The Hydrometeorological Design Studies Center (HDSC), Hydrology Laboratory, Office of Hydrologic Development, U.S. National Weather Service is updating its precipitation frequency estimates for the Ohio River Basin and surrounding states. Current precipitation frequency estimates for this area are contained in *Technical Paper No. 40* "Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years" (Hershfield 1961), *NWS HYDRO-35* "Five- to 60-minute precipitation frequency for the eastern and central United States" (Frederick et al 1977) and *Technical Paper No. 49* "Two- to ten-day precipitation for return periods of 2 to 100 years in the contiguous United States" (Miller et al 1964). The new study includes collecting data and performing quality control, compiling and formatting datasets for analyses, selecting applicable frequency distributions and fitting techniques, analyzing data, mapping and preparing reports and other documentation.

The study will determine annual all-season precipitation frequencies for durations from 5 minutes to 60 days, for return periods from 2 to 1000 years. The study will review and process all appropriate rainfall data for the study area and use accepted statistical methods. The study results will be published as a Volume of NOAA Atlas 14 on the Internet with the additional ability to download digital files.

The study will produce estimates for 13 states. Parts of nine additional bordering states are included to ensure continuity across state borders. The Susquehanna River and Delaware River Basins are included in the study area. The core and border areas, as well as tentative regions now used in the analysis, are shown in Figure 1.

Figure 1. Updated Ohio River Basin study area and region boundaries.

2. Highlights

Project Leader of the Ohio River Basin Study, Eloisa Raynault, has resigned. Budget constraints preclude replacing her resulting in an extension of the project schedule. Additional information is provided in Section 5.1, Personnel Change and 6, Projected Schedule.

Software was refined and automated to adjust quantiles for co-located hourly and daily data across all durations and frequencies. Software to compute and adjust confidence limits for co-located stations was also written. Software to carry quantile estimates of hourly stations out to 48-hours was completed. Additional information is provided in Section 4.1, Software Updates.

Regions have been examined for appropriate subdivisions to yield better results. The original 16 regions have been subdivided into roughly 50 smaller homogeneous regions. Additional information is provided in Section 4.2, L-moment Analysis.

Empirical plots were used during the subdivision process to assess the accuracy of chosen distributions to fit observed empirical frequencies, particularly for at-site stations. Additional information is provided in Section 4.3, Distribution Selection.

The Spatial Climate Analysis Service (SCAS) delivered a 14-page interim report to HDSC on December 24, 2002 describing the production of the draft 1-hour and 24-hour "index flood" rainfall grids for the Semiarid Southwest study using PRISM.   A minor change was made to the Cascade, Residual Add-back (CRAB) precipitation frequency grid derivation procedure to prevent multiple filtering as longer return frequencies are generated. Lastly, a final map/grid deliverable list was developed. Additional information is provided in Section 4.4, Spatial Interpolation.

In addition to the 12-hour, 24-hour, and 4-day durations, it was decided that temporal distributions of extreme rainfall would be produced for the 6-hour duration. Additional information is provided in Section 4.5, Temporal Distribution.

Seasonal information will be presented graphically as percentages of "exceedences" that occur in each month for a given region for 2-year, 10-year, 25-year, 50-year, and 100-year return frequencies. The software for the 1-hour and 24-hour durations has been written and preliminary graphs have been incorporated into the Precipitation Frequency Data Server. Additional information is provided in Section 4.6, Seasonal Graphs.

In order to accommodate all of the Precipitation Frequency Data Server and geospatial files, the allocated disk space for the PFDS was increased. The PFDS output was also

modified to include "seasonal exceedence graphs."   Additional information is provided in Section 4.7, Precipitation Frequency Data Server.

Progress towards the development of depth-area-duration (D-A-D) reduction relationships for areas from 10 to 400 square miles continues. The initial computer programming to quantify the spatial variation of storms used in the D-A-D analysis has been completed and tested successfully on two study areas. The second phase of the programming to perform the actual D-A-D curve fitting is nearly complete. Additional information is provided in Section 4.8, Spatial Relations (Depth Area Duration Study).

3. Status

3.1 Project Task List

The following checklist shows the components of each task and an estimate of the percent completed per task. Past status reports should also be referenced for additional information.

Ohio River Basin study checklist [estimated percent complete]:

Data Collection, Formatting and Quality Control [100%]:
- Multi-day
- Daily
- Hourly
- 15-minute
- N-minute

As data issues may arise in subsequent tasks, quality control is essentially a continuous process.

L-Moment Analysis/Frequency Distribution for 5 min. to 60 days and 2 to 1000 years [75%]:
- Multi-daily
- Daily
- Hourly
- 15-minute
- N-minute

Regions have been subdivided, except regions 4 and 2. Once these are finalized, all durations and return frequency quantile estimates will be computed and adjusted for internal consistency.

Spatial Interpolation [5%]
- Create mean annual maximum (a.k.a. "index flood") grids with PRISM for all durations from 60-minute to 60-days
- Apply a precipitation frequency map derivation procedure, known as the cascade residual add-back (CRAB) procedure to create a total of 162 grids. The same procedure will be used to create 162 upper and 162 lower bound precipitation frequency grids (see Section 4.3, Spatial Interpolation).
- Apply study-wide conversion factor to the 1-hour precipitation frequency grids to calculate the n-minute (5-, 10-, 15-, and 30-minute) grids.

Peer Reviews [0%]:
- External peer review of point precipitation frequency estimates
- External peer review of spatially interpolated grids

Data Trend Analysis [0%]
- Analyze linear trends in annual maxima and variance over time
- Analyze shift in means of annual maxima between two time periods (i.e., test the equality of 2 population distribution means)

Temporal Distributions of Extreme Rainfall [75%]
- Assemble hourly data by quartile of greatest precipitation amount and convert to cumulative rainfall amounts for each region
- Sort, average and plot time distributions of hourly maximum events by storm area, quartile and duration

Temporal distributions for 12- and 24-hour durations are complete. Work remains to compute the 4-day and 6-hour durations.

Deliverables [45%]
- Prepare data for web delivery
- Prepare documentation for web delivery
- Write hard copy of Final Report
- Publish hard copy of Final Report

A detailed outline of the final documentation is complete for the Semiarid Study requiring only minor modification for the Ohio Project. The Precipitation Data Frequency Server (PFDS) has been modified to include seasonal graphs.

Spatial Relations (Depth Area Duration Study) [60%]
- Obtain hourly data from dense-area reporting networks
- QC and format data from dense networks
- Compute maximum and average annual areal depth for each duration from stations for each network
- Compute maximum to average depth ratio for all durations and networks and plot
- Prepare curves of best fit (depth area curves) for each duration and network
- Combine all stations from all study areas to compute the ratio of maximum to average depth for all durations and networks and plot
- Examine differences in individual D-A-D curve plots for durations and study areas compared to those for combined study area data plots

D-A-D reductions for areas from 10 to 400 square miles are being updated for the entire United States and will be presented in a separate volume of NOAA Atlas 14.

4. Progress in this Reporting Period

4.1 Software Updates

Internal consistency software was refined to include all durations and all return frequencies. When internal consistency adjustments are made in the quantiles for one return frequency, it is necessary to adjust all frequencies to maintain realistic results (i.e., so that 50-year estimates are not greater than 100-year estimates). This is particularly true at shorter return frequencies because ratios of small values can be large, leading to large adjustments. Software to carry quantile estimates of hourly stations out to 48-hours was also completed.

Software was created to generate a complete list of co-located hourly and daily stations with their assigned regions and run existing adjustment software on all regions at once with minimal manual input. This provides a more efficient and less error-prone mechanism for completing the precipitation frequency analysis for a given study area. In addition, software to compute and adjust confidence limits for co-located stations was written.

4.2 L-moment Analysis

A region by region examination of 24-hour L-moment results and appropriate subdivisions is currently underway. The original 16 regions of the study have been subdivided into 50 regions and 8 at-site stations. Only regions 4 and 2 are pending. Table 1 provides the subdivision details for each original region. Please see Figure 1 for a spatial illustration of the subdivisions.

During the subdivision process, stations in regions are re-grouped into smaller homogeneous regions based on climatology, topography, real data checks and statistical results. In the real data check, large discrepancies between 100-yr estimate and maximum observed rainfall are carefully examined. Effort is made during the subdivision process to mitigate such discrepancies that could be caused by (1) sample error due to small sample sizes, or (2) regionalization that does not reflect climatology.

Table 1. Subdivision Progress for original 16 Ohio River Basin regions.

| Region	Subdivisions Progress
1	re-grouped
2	re-grouping pending
3	5 subdivisions
4	2 subdivisions pending
5	6 subdivisions
6	no change
7	3 subdivisions
8	re-grouped
9	3 subdivisions
10	8 subdivisions
11	7 subdivisions
12	re-grouped
13	re-grouped
14	no change
15	5 subdivisions
16	5 subdivisions
at-site	8 stations pending

4.3 Distribution Selection

Of the five 3-parameter distributions examined, the Generalized Extreme Value (GEV) distribution is the best-fit distribution for 24-hour estimates throughout most of the study area. We developed software to generate empirical frequency plots that help assess the accuracy of a chosen distribution to fit an observed empirical frequency at a station (see Figure 2). We sometimes use empirical frequency plots in the subdivision process to judge the appropriate region for a given station.

The plots are also used to assess the appropriateness of at-site stations. Because at-site stations are often statistical exceptions in a region and ultimately influence the spatial pattern in an area, they are carefully investigated. Figure 2 shows the empirical frequency plot for the at-site station, Norwalk WWTP, OH (33-6118), which has over

100 years of data. This example illustrates how empirical plots are used for assessing at-site stations. The plot shows that retaining the station in region 11SE with the regional best-fit distribution, Generalized Extreme Value distribution (GEV) produces lower estimates at longer return frequencies than going to an at-site analysis using the best-fitting distribution, Generalized Log-Normal distribution (GLO). The higher estimates at longer return frequencies from the at-site analysis are more consistent with this station's empirical frequency. Therefore, this station will be analyzed at-site, rather than within the region.

Figure 2. Empirical frequency plot for Norwalk WWTP, OH (33-6118).

Empirical Freq. vs Theoretical Prob.
(OH-region11SE: 33-6118. 24h-AMS)
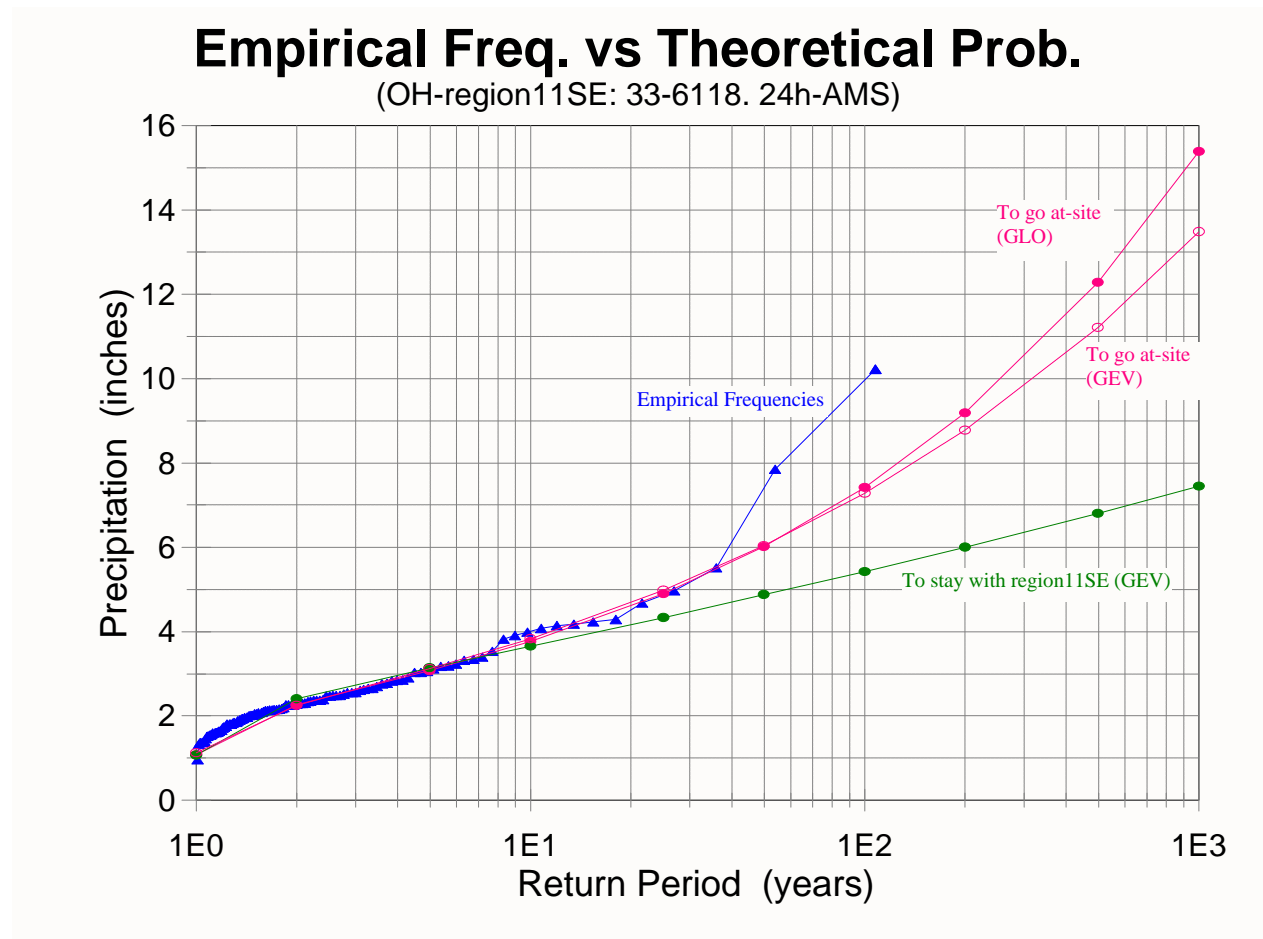
4.4 Spatial Interpolation

The Spatial Climate Analysis Service (SCAS) at Oregon State University delivered a 14-page interim report to HDSC on December 24, 2002. The report describes the work performed to produce the draft 1-hour and 24-hour "index flood" rainfall grids for the Semiarid Southwest study using the PRISM model (Parameter-elevation Regressions on Independent Slopes Model). This production provides the foundation for the Ohio "index flood" rainfall grids. Although the interim report deals with the Semiarid grids, the Ohio grids will essentially be created using the same process. A few adjustments to the PRISM process will be made for the Ohio project, namely to account for coastal effects that the Semiarid project did not have.

A minor change was made to the Cascade, Residual Add-back (CRAB) precipitation frequency grid derivation procedure (see CRAB description in 12th Progress Report, Section 4.3). Instead of using a final, slightly filtered grid as the predictor for the subsequent grid, the CRAB procedure now maintains and uses unfiltered grids for its predictor grids throughout the process. The final grids for each precipitation frequency estimate are still slightly filtered, but because filtering is not done on the predictor grid, a greater level of spatial detail is maintained and portrayed in the resulting grids/maps. Lastly, a final map/grid deliverable list was developed (see Table 2). All durations and return frequencies will have ArcInfo ASCII grids and ESRI shapefiles of isohyets. Initially, a subset of durations and return frequencies will have state-specific printable cartographic maps in PDF format with the remaining durations to be produced as time permits in the future (indicated in table by asterisks).

Table 2. List of all map/grid deliverables.

|	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr	1000-yr
5-min	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
10-min	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
15-min	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
30-min	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
60-min	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	G, S, SM*	G, S, SM*	G, S, SM*
120-min	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
3-hr	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
6-hr	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	G, S, SM*	G, S, SM*	G, S, SM*
12-hr	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
24-hr	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	G, S, SM*	G, S, SM*	G, S, SM*
48-hr	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
4-day	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
7-day	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
10-day	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	G, S, SM*	G, S, SM*	G, S, SM*
20-day	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
30-day	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
45-day	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
60-day	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	G, S, SM*	G, S, SM*	G, S, SM*

G = ArcInfo ASCII grid
S = ESRI shapefile of isohyets
SM = State-specific printable cartographic map (PDF format)
SM* = State-specific printable cartographic map (PDF format) as time permits

4.5 Temporal Distribution

In addition to the 12-hour, 24-hour, and 4-day durations, it was decided that temporal distributions of extreme rainfall would be produced for the 6-hour duration. Distributions are grouped according to the quartile of time in which the most rain fell. All quartiles from each duration, 6-hour, 12-hour, 24-hour and 96-hour will be presented in the final document. In addition, a single plot combining all four quartiles into a single distribution will be presented for each duration. Figure 3 shows an example of a temporal distribution for 96-hour duration events in which 1st quartile precipitation dominated.

Figure 3. Example of 1ˢᵗ quartile temporal distribution of 96-hour duration events.
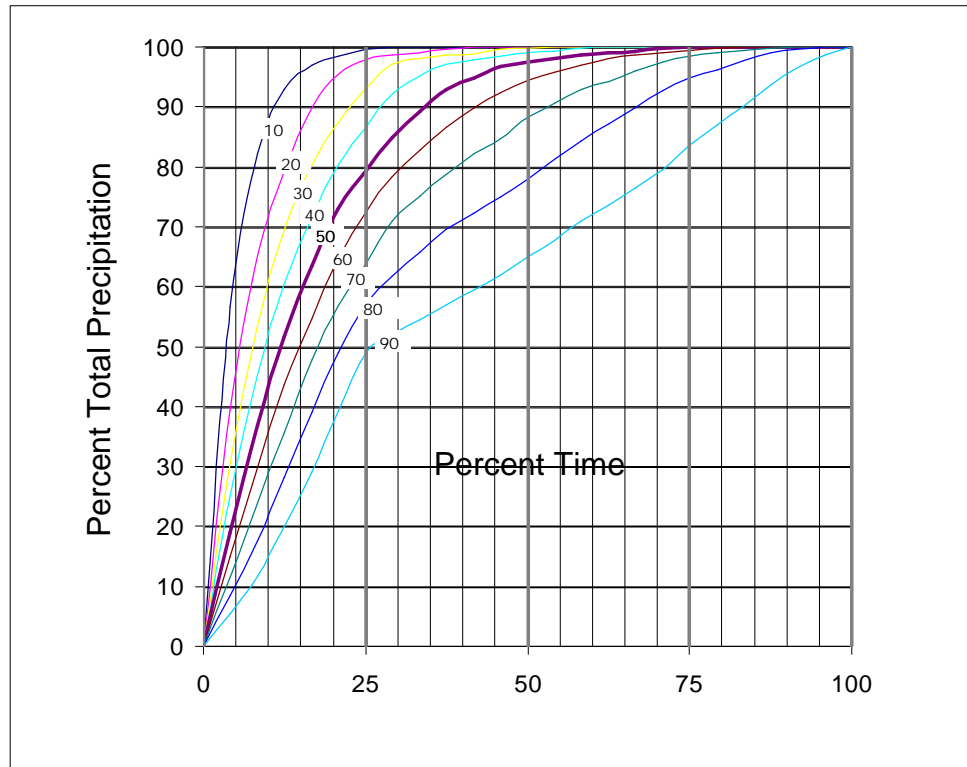

4.6 Seasonal Graphs

Seasonal information will be presented graphically as percentages of "exceedences" that occur in each month for a given region. "Exceedences" are events that exceed corresponding 2-year, 10-year, 25-year, 50-year, and 100-year precipitation frequency estimates at a given station and duration. The percentage is derived from the total number of cumulative years for all stations in a given region.   Theoretically, 50% of the events should exceed the 2-year estimates, 4% should exceed the 25-year estimates, 2% should exceed the 50-year estimates and only 1% should exceed the 100-year estimates.

Exceedence graphs will be presented for the 1-hour, 24-hour, 48-hour and 10-day durations. Figure 4 is an example of an exceedence graph where extreme precipitation occurs primarily in July, August and September. The software for the 1-hour and 24-hour durations has been written and preliminary Semiarid graphs have been incorporated into the Precipitation Frequency Data Server. Work is nearly complete for the 48-hour and 10-day duration software.

Figure 4. Example of 60-minute seasonal exceedence graph.
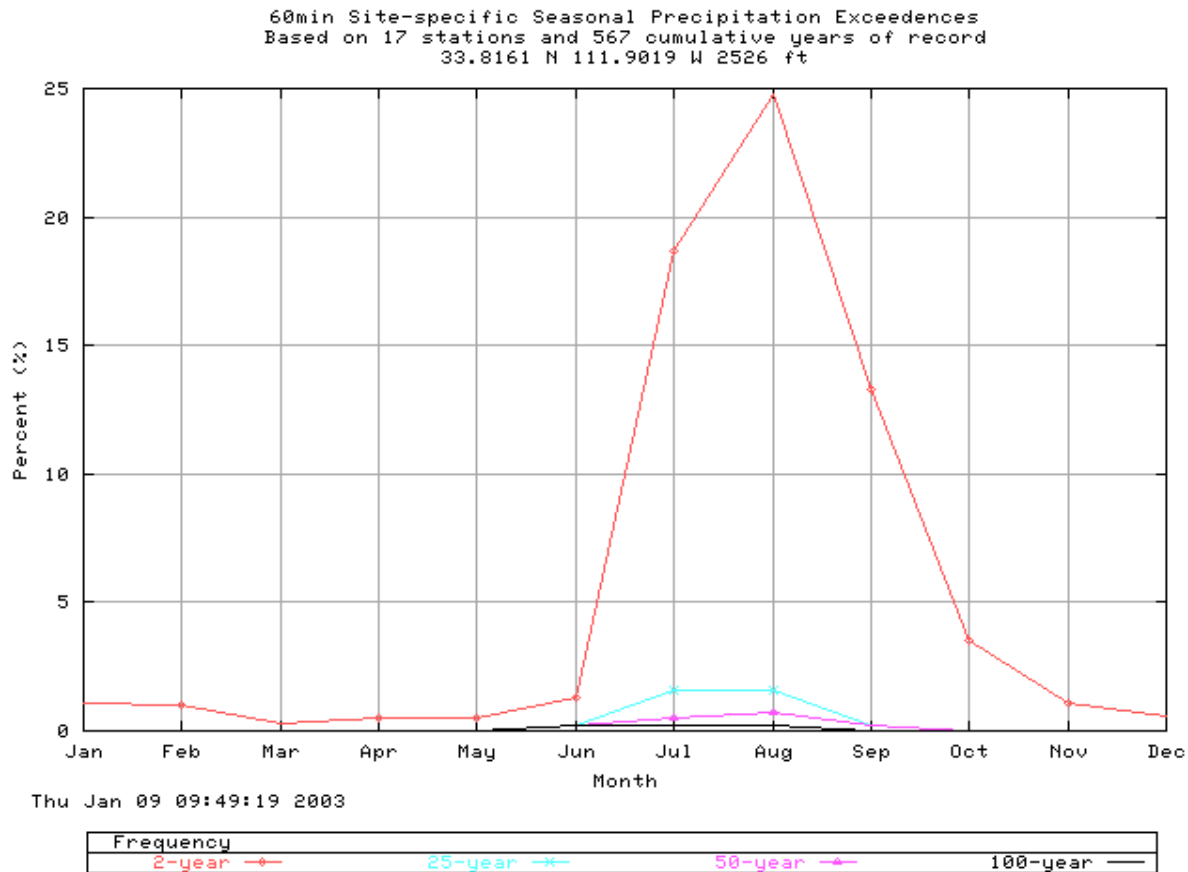
4.7 Precipitation Frequency Data Server

In order to accommodate all of the PFDS and GIS compatible files, the allocated disk space for the PFDS was increased to 30 gigabytes. Our calculations suggest that this will be ample disk space to accommodate all of our current precipitation frequency projects.

The PFDS output was also modified to include links to regional "seasonal exceedence graphs" (see Section 4.6, Seasonal Graphs). The total number of stations and the total number of cumulative years used in the calculations are provided in the graph title.

4.8 Spatial Relations (Depth-Area-Duration Study)

Progress towards the development of depth-area-duration (D-A-D) reduction relationships for area sizes of 10 to 400 square miles continues. The initial computer programming to quantify the spatial variation of storms used in the D-A-D analysis has been written, tested successfully, and performed on two study areas. The second phase of the programming to perform the actual D-A-D curve fitting is nearly complete and will be tested in January on two study areas. There has been no change in the D-A-D study areas that will be used to develop the final D-A-D curves (see previous progress report). Currently, there are 12 study areas scattered throughout the conterminous United States that have been quality controlled. Three other study areas may be added once the D-A-D curves are developed for the existing study areas. These three study areas will be used if it is determined that a single curve for the entire U.S. is insufficient and separate curves need to be developed.

5. Issues

5.1 Personnel Change

As of December 5, 2002, Eloisa Raynault resigned from HDSC. Eloisa was a civil engineer who was the project lead for the Ohio River Basin and Surrounding States Precipitation Frequency Study. A replacement will not be hired due to budget constraints. Debbie Todd will take on the responsibility of project lead for the Ohio River Basin Study. Unfortunately, Eloisa's departure has forced a delay in project schedules.

5.1 AMS Annual Meeting

HDSC is presenting four papers/posters at the 83rd American Meteorological Society Annual Meeting in February of 2003. The papers include *Updating NOAA/NWS Rainfall Frequency Atlases*, which will give an overview of our approach, *Updated Precipitation Frequencies for the Semiarid Southwest United States*, which will present selected results from the Semiarid study, *Updated Precipitation Frequencies for the Ohio River Basin and Surrounding States*, which will present selected results from the Ohio study, and *NOAA/NWS Precipitation Frequency Data Server*, which will present the PFDS in detail.

6. Projected Schedule

The following list provides a tentative schedule with completion dates. Brief descriptions of tasks being worked on next quarter are also included in this section.

> Data Collection and Quality Control [Complete]
> Temporal Distributions of Extreme Rainfall [February 2003]
> L-Moment Analysis/Frequency Distribution [February 2003]
> Peer Review of Spatially Distributed Point Estimates [April 2003]
> Spatial Interpolation [May 2003]
> Precipitation Frequency Maps [June 2003]
> Web Publication [July 2003]
> Spatial Relations (Depth Area Duration Studies) [February 2003]

6.1 L-Moment Analysis

A comprehensive L-moment statistical analysis will be completed during the next quarter for all datasets for all durations and all finalized regions. Partial duration series will be analyzed so that conversion factors from annual maximum series to partial duration series can be developed. Software will be written to compute confidence intervals associated with each precipitation frequency estimate and adjust for internal consistency during the next quarter.

6.2 Spatial Interpolation

During the next quarter, HDSC will deliver the point mean annual maxima (a.k.a. "index flood") values to the Spatial Climate Analysis Service (SCAS) at Oregon State University for the 60-minute and 24-hour durations. SCAS will use PRISM to spatially interpolate the values to grids, which will then be used by HDSC to derive the precipitation frequency maps. After a peer review of the results, work will begin on the remaining durations and return frequencies.

6.3 Peer Review

A single peer review of the precipitation frequency point estimates and draft maps will occur during the next quarter. The review will include the point precipitation frequency estimates and associated confidence intervals for all durations (5-minute to 60-day) and all return frequencies (2-year to 1000-year). The review will cover all stations, even those outside the core area that is the focus of the Study. The purpose for including the non-core area is to provide continuous data across the exterior study area border. Comments pertaining to data in non-core areas will be addressed according to their influence to the core study area . The review will also include the spatially interpolated grids for the following:
1.   1-hour mean annual maximum maps ("index flood" maps)
2.   1-hour 100-year precipitation frequency maps
3.   24-hour mean annual maximum maps ("index flood" maps)
4.   24-hour 100-year precipitation frequency maps

6.4 Trend and Shift Analysis

The dataset will be analyzed for any trends or shifts in annual maxima through time. T-tests will be used to detect any linear trends in annual maxima or in variance, while t-tests, Mann-Whitney tests and Chi-squared tests will be used to determine any shifts in means of annual maxima.

6.5 Temporal Distributions of Extreme Rainfall

Temporal distributions for storms of 6-hour and 4-day duration will be computed during the next quarter.

6.6 Spatial Relations (Depth-Area-Duration Study)

Software development for the D-A-D computations will be completed in the next quarter and the computations will be performed for 12 study areas.

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